L/C Meter
User Guide

Important:	**Always use or print this document in colour as there are references to the colours of components. Errors may occur otherwise.**

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Contents

Document History

Issue	Date	Changes
1	12th June 2009	First Issue
2	13th July 2009	Assembly step 5.16 – changed "cable" to "cable tie"
3	1st November 2009	Assembly step 5.13 – added alternate orientation marks for K1

L/C Meter User Guide

This section explains how to use your L/C Meter. If you have not yet built the meter, proceed to the Kit Assembly Instructions section.

If you have any questions or are unsure about what is meant by anything, please email support@debuginnovations.com and we will be pleased to assist you.

Overview

An L/C meter is a very useful piece of test equipment. Most people have access to a multi-meter which can measure resistance. Some multi-meters have a basic capacitance measuring facility and low cost commercial capacitance meters are also available. However inductance (L) measurement is a lot trickier. Most low cost commercial inductance meters are designed for measuring power transformers and the like with inductances in the milli-Henry and Henry range. For RF work we need a meter that works down to micro- and even nano-Henrys. This meter is specifically designed for measuring small value capacitors (<1uF) and inductors (<100mH). These are the types of components used in RF designs.

The meter works by measuring the resonant frequency of an LC circuit where either the L or the C is the component to be measured. This method has the advantage that very small values can be measured accurately – L's down to a few nH and C's to a few pF. It also means that the L/C is measured at high frequencies – the sort of frequency you are going to use them at.

Although similar to many designs on the internet, this meter has completely new software and a unique connector for higher accuracy. Auto-calibration, auto-zeroing and auto-ranging make this design simple and reliable.

The major parts of the L/C Meter are shown below:
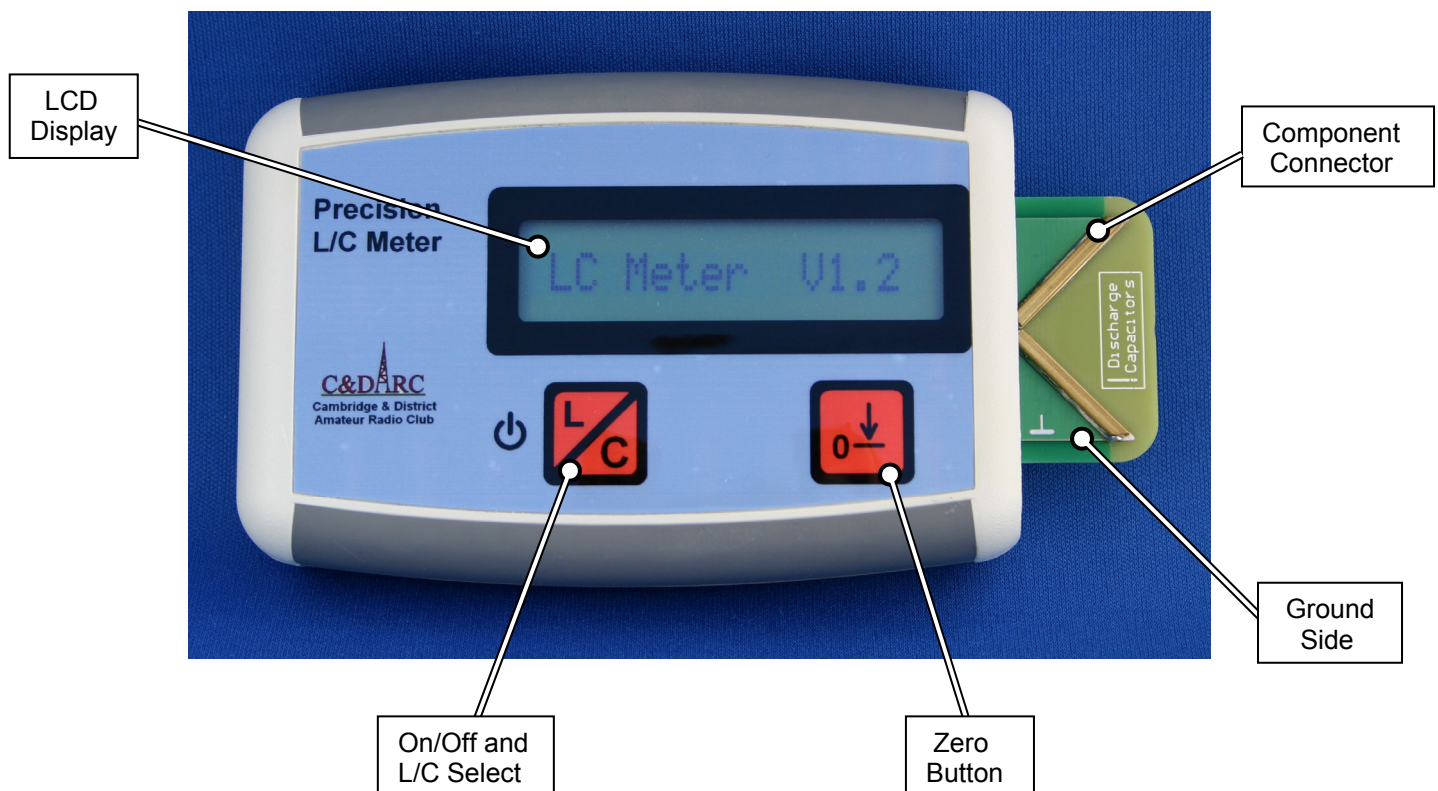
Power On/Off

To turn on the meter, press the L/C button once. The LCD display will show a sign-on message with the software version followed by "Calibrating…". During the calibration procedure, do not touch or place any components on the component connector. The meter starts up in capacitance measuring mode.

To turn off the meter, hold down the L/C button for 2 seconds. When the display goes blank release the button. If the meter is not used for 2 minutes, it will turn off automatically to preserve the battery.

Basic Operation

Basic operation is simplicity itself. The L/C button switches between inductance (L) measuring mode and capacitance (C) measuring mode. The selected mode is indicated by an L: or C: at the left hand end of the display. With no component connected, in C mode, 0pF is indicated and in L mode ----- is indicated. The zero button zeros the display.

The component connector is designed to accommodate a wide range of different sized components. Small surface mount devices can be pushed up to the point of the connector using a non-conductive tool. Larger leaded devices should have their leads bent at right angles to the connector bar – this will stop the component sliding along the connector as pressure is applied.

Be careful not to touch the component leads or any conductive parts of the component as this will change the reading. If you have to touch the leads e.g. when testing variable capacitors where the shaft is connected to one side, make sure it is the ground side as indicated by the ground symbol on the PCB (see photo).

Measuring Capacitance

To measure a capacitor, first switch to capacitance mode (press the L/C button until you see C: on the left of the display). With no component connected, the display should read 0pF – if it doesn't, press the zero button.

Next connect your capacitor to the component connector taking care not to touch the leads. The value will be shown on the display. The range is automatically chosen and the value is displayed in the appropriate units. If the component is on the borderline between two ranges, the meter may switch ranges as you move the component in the connector but built-in hysteresis ensures the meter will not 'hunt' between ranges.

Electrolytic capacitors do not resonate well in an LC circuit and will not give a reliable reading with this meter. Non-electrolytic capacitors can be measured from a few pF up to about 1uF. Over Range is indicated at 1.5uF. Capacitors with significant ESR or inductive connections or other impure capacitance will give erroneous readings. This may happen with old components that have degraded or become leaky. Most modern commercial components give reliable readings but you may be surprised how inaccurate they can be – some capacitors have tolerances specifications like +80/-20% which means they can be almost twice their nominal value.

With a purely capacitive component the accuracy of the reading is about +/- 1% except for values at the extreme ends of the range e.g. <10pF.

<div style="border: 2px solid red; text-align: center; color: red;">

WARNING
Ensure that capacitors are fully discharged before trying to measure them !!

</div>

Measuring Inductance

To measure an inductor (a coil), first switch to inductance mode (press the L/C button until you see L: on the left of the display). With no component connected, the display should read -----.

Next connect your inductor to the component connector taking care not to touch the leads. The value will be shown on the display. The range is automatically chosen and the value is displayed in the appropriate units. If the component is on the borderline between two ranges, the meter may switch ranges as you move the component in the connector but built-in hysteresis ensures the meter will not 'hunt' between ranges.

Inductors with a low Q do not resonate well in an LC circuit and will not give a reliable reading with this meter. Coils in packages such as the TOKO tin-can type can also contain other components notably capacitors in parallel with the inductors. Obviously these will not give reliable readings.

Inductors from around 100nH to over 100mH can be measured accurately with this meter though stray inductance can be challenging at less than 1uH. Try to measure close to the component body rather than at the ends of the leads.

One situation in which this meter is particularly useful is when winding your own coils. A little known fact is that cores such as the popular toroid types used in amateur radio designs have quite a wide tolerance of +/-20%. This means that you may have to wind 20% more or less turns to get the inductance you need – something that can be very important for oscillators or filters. This meter takes the guess work out of winding you own coils.

With a purely inductive component the accuracy of the reading is about +/- 1% except for values at the extreme ends of the range e.g. <100nH.

The Zero Button

The zero button has several uses. It can be used to zero out small inaccuracies when measuring low value components (see next section) or it can be used for deliberate adjustments.

For example, to select matching components from a batch of 1nF capacitors, first measure a capacitor then, with the component still connected, press the zero button. When you remove the capacitor the display will read -1nF. Connect the next capacitor and the display might read say -10pF which means the second capacitor is 10pF lower in value than the first (990pF if the first capacitor was exactly 1000pF). If the reading is 12pF, that means the capacitor is 12pF higher than the first part.

When switching from L mode to C mode or vice versa, any offset caused by pressing the zero button is automatically reset (equivalent to switching the unit off and on again).

Measuring Low Value Components

Theoretically the unit should read 0pF on power on. In practice the oscillator frequency drifts slightly and the reading changes in response. If you are trying to measure components with very low values e.g. <10pF and <100nH, leave the unit on for a few minutes (you may have to keep switching it on after auto-power off) to stabilise the oscillator, then recalibrate (switch off and on), then take the reading.

With low values, it is important to avoid stray inductance and capacitance. Stray capacitance is calibrated out automatically by the meter at power-on. Stray inductance is compensated for by the software based on measurements of the PCB characteristics. However this is not enough for measurements of inductors below about 100nH. The best way is to warm up the unit as described above then zero the inductance range using a zero ohm resistor or piece of wire in the gap between the component connector bars. Then the inductor under test can be measured. When measuring both small capacitors and inductors, it is very important to keep your hands well away from the connector to avoid stray capacitance affecting the reading.

Test Mode

To enter test mode, start with the unit turned off. Hold down the zero button and turn on the unit. After a few seconds the display will show -- Test Mode -- and then display the oscillator frequency.

Pressing the zero button will toggle between Fosc and Fcal:

Fosc is the oscillator frequency with the calibration capacitor **disconnected** from the circuit. **Fcal** is the oscillator frequency with the calibration capacitor **connected** to the circuit.

Pressing the L/C button will exit test mode and go into normal operation mode.

WARNING: Auto-power off does not function in test mode – the unit will stay on until the battery goes flat.

Error Messages

If the unit fails you may get one of the following error messages:

Oscillator Fail is displayed when the oscillator doesn't start at power-on. This may happen if you leave a component connected or a short develops on the component connector.

Calibration Fail is displayed if the calibration capacitor doesn't have the expected effect on the oscillator frequency during the calibration process. Again it can be caused by components on the component connector. If this happens and you are sure there is no interference from external components, put the unit in test mode and check the frequency with the calibration capacitor in and out of circuit – Fcal should be between 55 and 70% of Fosc.

Error messages are displayed for 20 seconds or until you press the L/C button, upon which the unit turns off.

Replacing The Battery

The unit is powered from a 9V PP3 battery. It is accessed through a slide out panel on the back of the box. Simply open the panel, pull the battery out and unclip the battery clip, then replace with a new battery.

Battery life is very good as power consumption is low and the unit powers off automatically after 2 minutes of inactivity.

LC Meter V1.2 Kit Assembly Instructions

This section gives step by step instructions on assembling and testing the kit. It is not a difficult kit to build except for soldering the component connector which is a little tricky, but can be done even by a novice if the instructions are followed carefully. Most people should be able to build the kit in under 5 hours. Seasoned builders will only require 2 to 3 hours. There are no surface mount components (unless you count the component connector).

If you have any questions or are unsure about what is meant by anything, please email support@debuginnovations.com and we will be pleased to assist you.

Step 1: Unpacking Your Kit

Your kit should come in a sealed package as shown below. These instructions are for PCB V1.2. Please check that your kit label says PCB V1.2.

Once opened you should have the following items. Ensure you have all the items before proceeding.

1. An envelope containing the top panel artwork
2. The pre-cut box (includes battery clip and box screws)
3. A peg used for soldering the component connector
4. The PCB V1.2
5. The LCD display
6. The 74LS75 chip
7. Relay K2
8. The PIC chip, its socket and relay K1
9. A bag containing the mechanical parts
10. A bag containing the rest of the electronic components

Step 2: Component Identification

First check you have the correct PCB version (V1.2). The version number is shown on the solder side of the PCB etched in the copper as shown below.

PCB Version Number
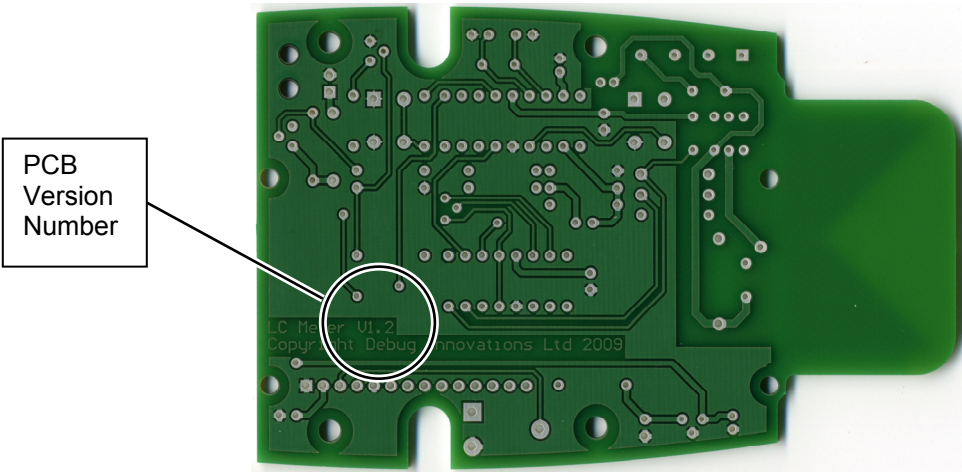
Open the bags and check you have all the components <u>on both parts lists</u> (see Appendices B1 & B2).
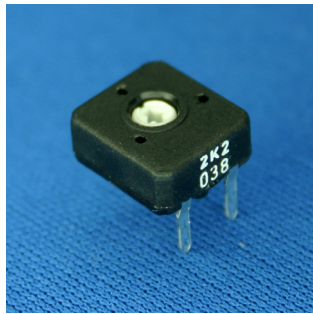
Resistors
All the resistors are through-hole types. There are 4 different values. Appendix G shows the resistor colour codes. If in doubt, measure them with a multi-meter.
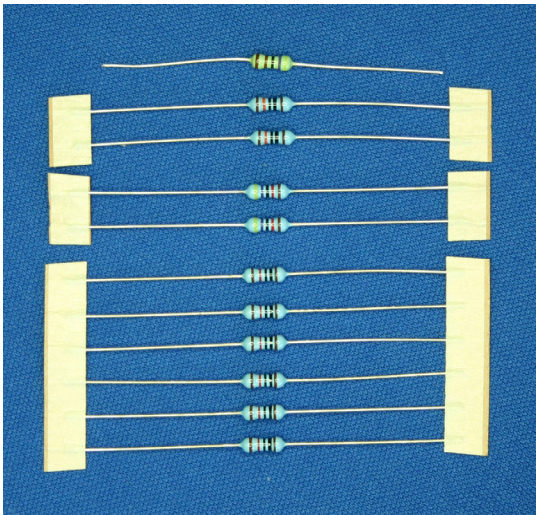
Designator	Value
R1-R5, R11	10K
R6, R7	100K
R8, R9	47K
R10	4K7

Variable Resistors

You should have one preset potentiometer.
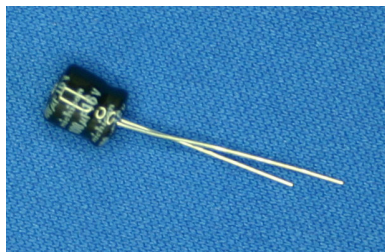

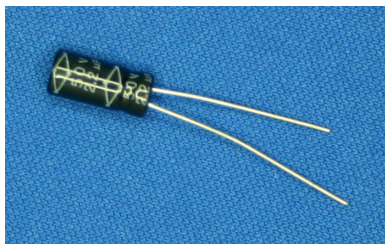| Designator	Value
VR1	2K2

Capacitors

All the capacitors should be identifiable from their markings. They may not be identical to the photos and may have different voltage ratings, as components from different manufacturers can look slightly different.
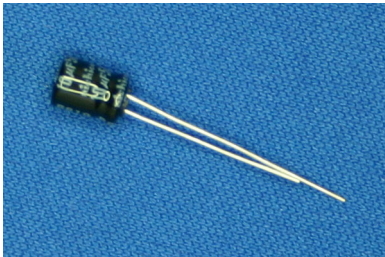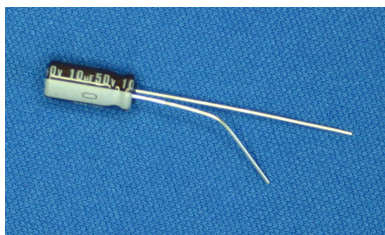

Designator	Value	Markings / Identification
C1	10uF	10uF, black in colour, short & stubby. Take care not to mix up with C4.

Designator	Value	Markings / Identification
C2	100uF	100uF, black in colour, short & stubby

Designator	Value	Markings / Identification
C3	2.2uF	2.2uF, black in colour

Designator	Value	Markings / Identification
C4	10uF, low ESR	10uF, brown in colour. Take care not to mix up with C1.
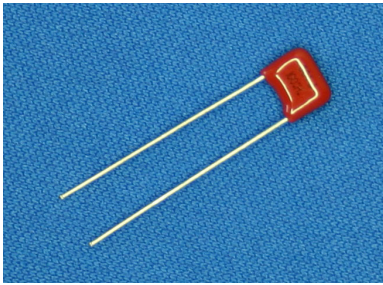
Designator	Value	Markings / Identification
C5	680pF	681J, red in colour
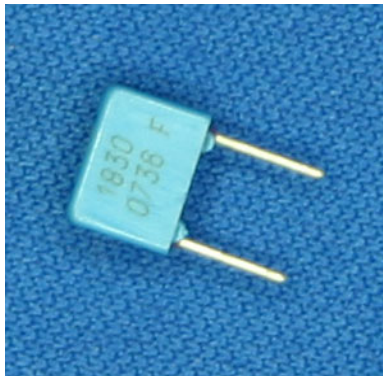
Designator	Value	Markings / Identification
C6	1nF 1%	1n0 on top edge, blue in colour
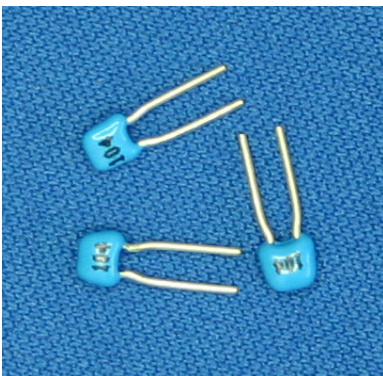
Designator	Value	Markings / Identification
C7-C9	100nF	104, blue in colour
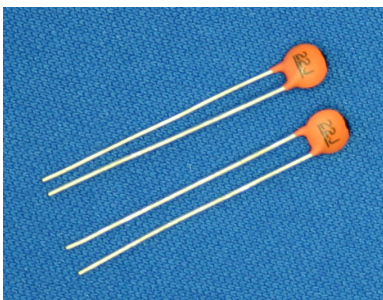
Designator	Value	Markings / Identification
C10 & C11	22pF	22J, orange in colour. Take care not to mix up with C12.
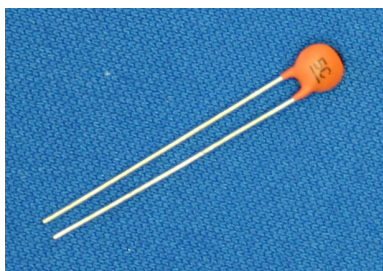
Designator	Value	Markings / Identification
C12	5pF	5C, orange in colour. Take care not to mix up with C10/C11.

Inductor

There is only one inductor. It looks like a fat resistor and has the same coloured bands.
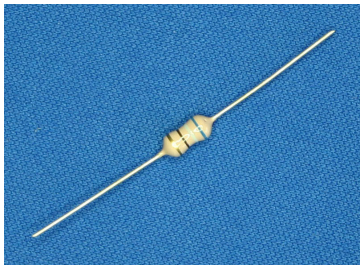
Designator	Value
L1	68uH

Diodes

You should have five diodes (two different types). The diodes are marked with the part number around their body. The striped end is the cathode.
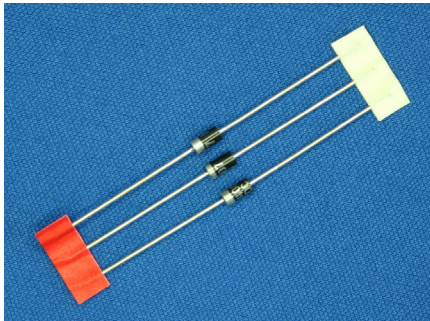
Designator	Type
D1 – D3	1N4007
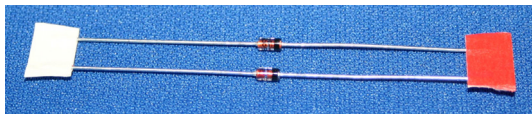
Designator	Type
D4 & D5	1N4148

Transistors

There are two transistors. They look very similar but they are clearly marked with the part number. Be careful not to confuse them with U2, which also looks the same.
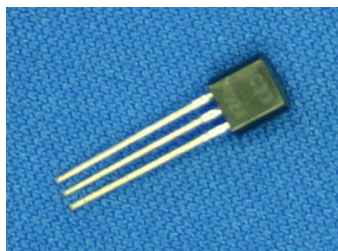
Designator	Type
Q1	BC337
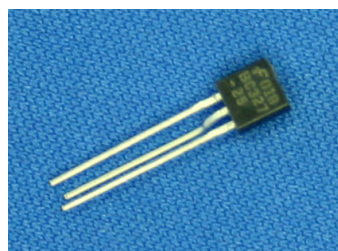
Designator	Type
Q2	BC327

Integrated Circuits
You should have three ICs and an IC socket. The ICs are marked with their part numbers.
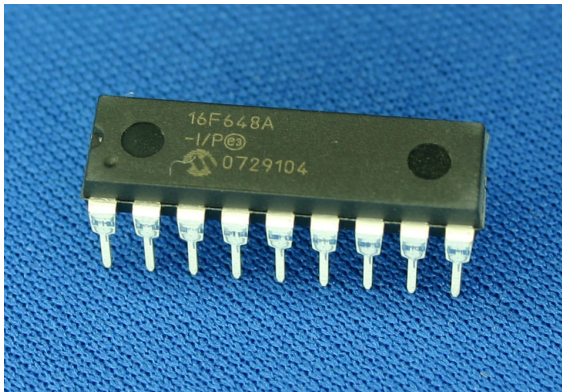
Designator	Type
U1	PIC16F648A (Programmed)
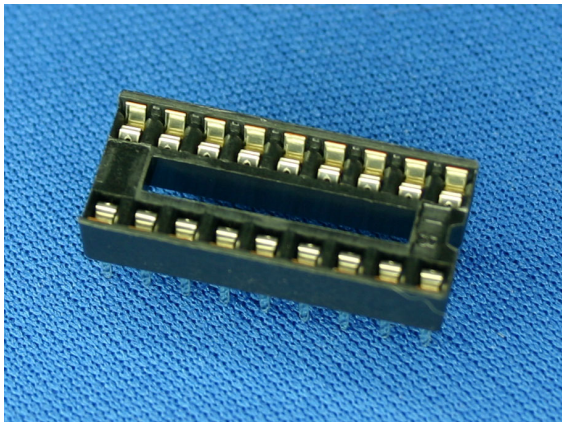
Designator	Type
ICSKT1	18 pin IC socket for U1

Designator	Type
U2	78L05
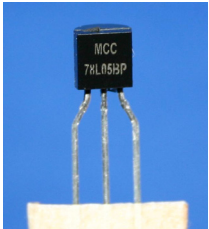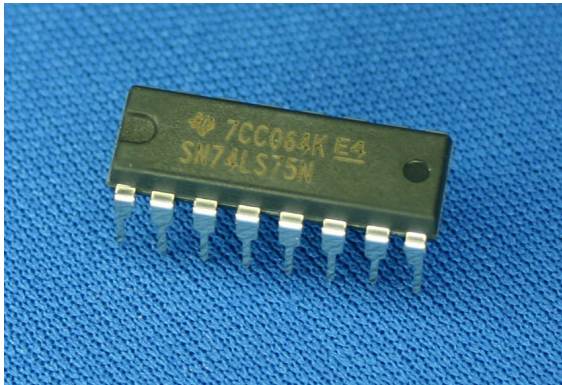
Designator	Type
U3	74LS75

U1 is supplied pre-programmed and is fitted in the IC socket. U3 must be soldered directly to the board to maintain clearance from the LCD display which is mounted above U3.

Crystal

You should have one quartz crystal.
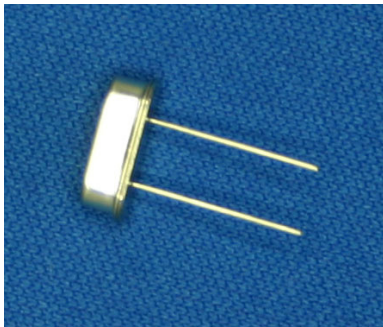
Designator	Value
Y1	4MHz

Relays

You should have two relays.
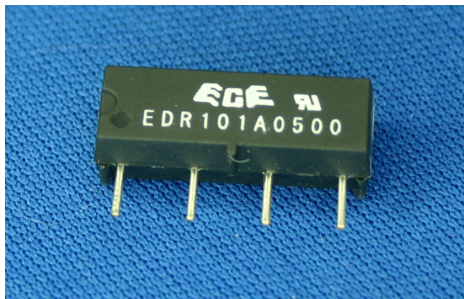
Designator	Type
K1	Reed Relay

Designator	Type
K2	Miniature Relay

Switches

You should have two push button switches.
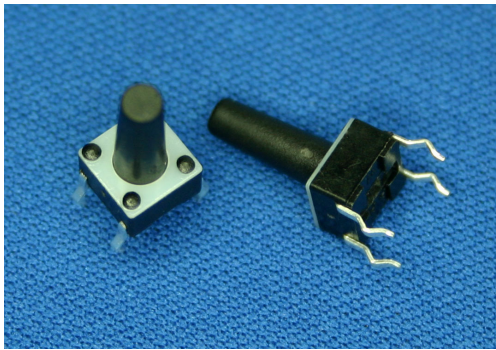
Designator	Type
SW1 & SW2	Push button

Connectors

There are 3 connectors.
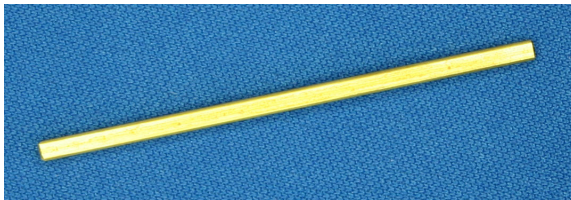
Designator	Type
J1	Component Connector made from square section brass tubing
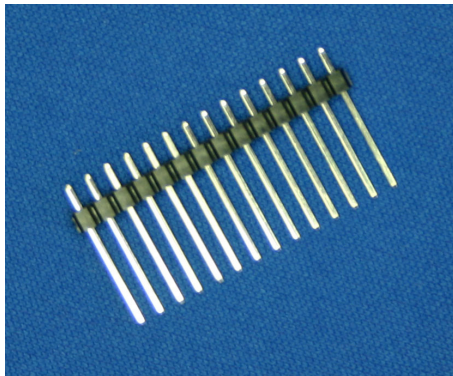
Designator	Type
J2	Display Connector
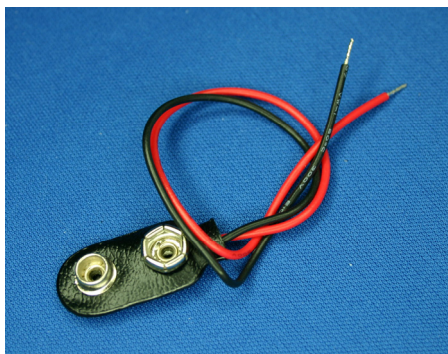
J3	Battery clip (supplied with case)

LCD Display
You should have an LCD display.
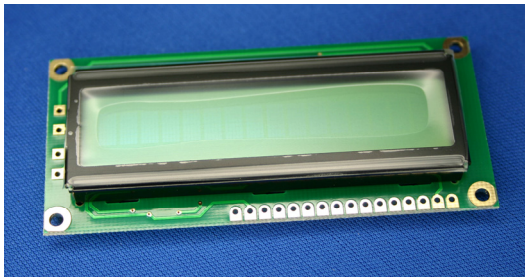
Designator	Type
DISP1	16 x 1 line Alphanumeric LCD

Pre-drilled Case
The case comes pre-cut in 3 parts and is held together with a pair of self-tapping screws.
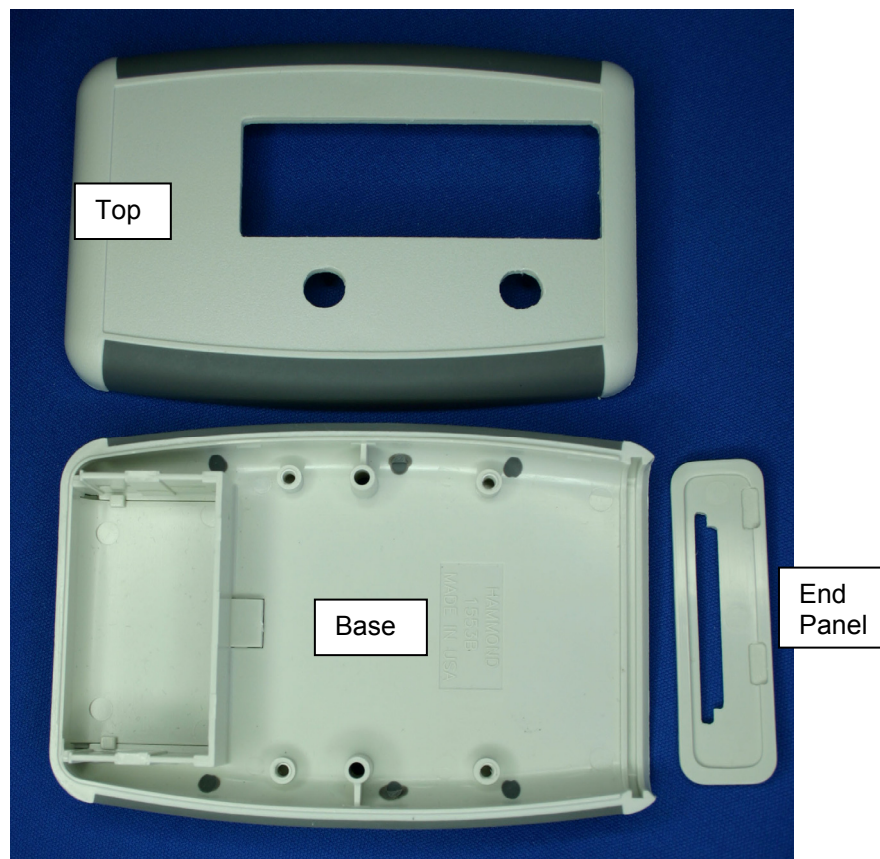
Mechanical Components
The mechanical components bag contains the following parts.

Mounting screws for PCB
(to screw PCB to box base)
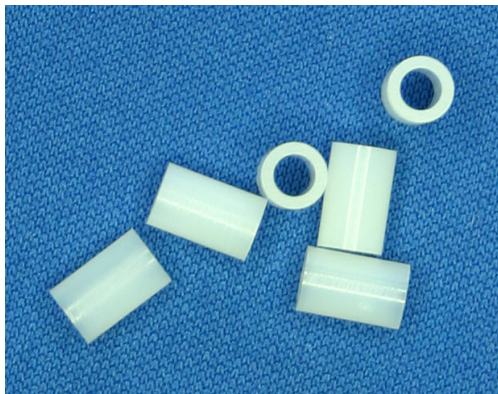
Display spacers x 4
Button standoffs x 2
These are the same part
used in 2 different places
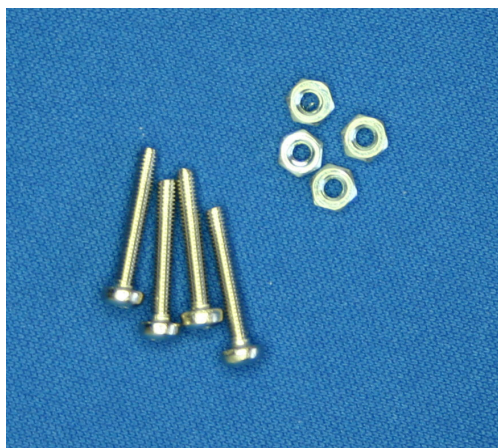
LCD Display screws and nuts
(to screw the LCD display to
the PCB)
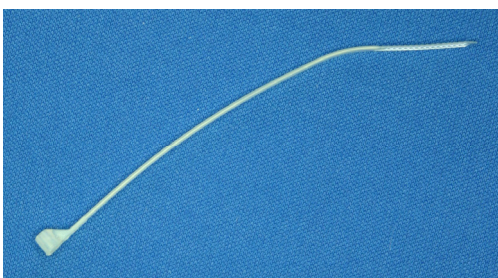
Battery clip cable tie

Step 3: Preparing For PCB Assembly

First read through the rest of the assembly instructions. The build is not difficult and should be easily completed in a day.

Before starting PCB assembly, ensure you have the following:

1. A large, clear, well lit working area. Use daylight if possible.

2. A fine tipped soldering iron and some thin solder. There are no SMD components but care must still be taken.

3. A multi-meter. If you spot a suspect solder joint or break a track, test it and repair it if necessary, before moving on.

4. Use a PCB assembly jig, if you have one.

Follow these basic tips for a good result:

1. Make sure your PCB is clean. If you have had your kit for a while, the plated areas of the PCB may have started to tarnish. This will make it harder to solder. A simple way to remove the tarnish is to rub the board with a standard pencil eraser.

2. Use only as much solder as necessary, particularly with the smaller parts.

3. Assemble the smallest components first, working up to the larger parts (the assembly instructions keep to this order).

4. When soldering large metal parts, turn up the iron temperature (if possible) and use a large bit, then use molten solder to spread the heat more evenly. Oh, and remember not to touch the hot component for quite a while!!

5. Observe anti-static precautions.

6. Most importantly, take your time.

Step 4: Component Connector Assembly

Before putting the 'regular' components on the PCB, you must first make and solder on the component connector. This is the hardest part of the build and shouldn't be rushed.

1. Take the brass bar and saw it in half with a hacksaw – you will end up with 2 pieces, each of which is approximately 25-30mm in length.

2. Cut / file one end of each piece diagonally at 45° until they are 23.5mm long on the long side as shown below.
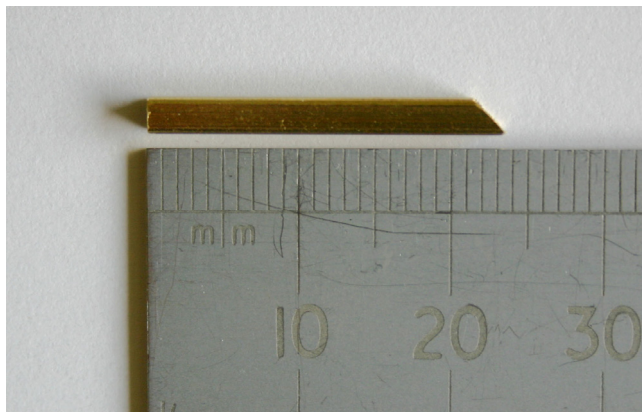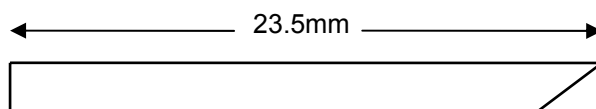
3. Polish the brass bars to make them easier to solder. The best thing to use is a polishing block such as Maplin part number HX04E shown to the right.
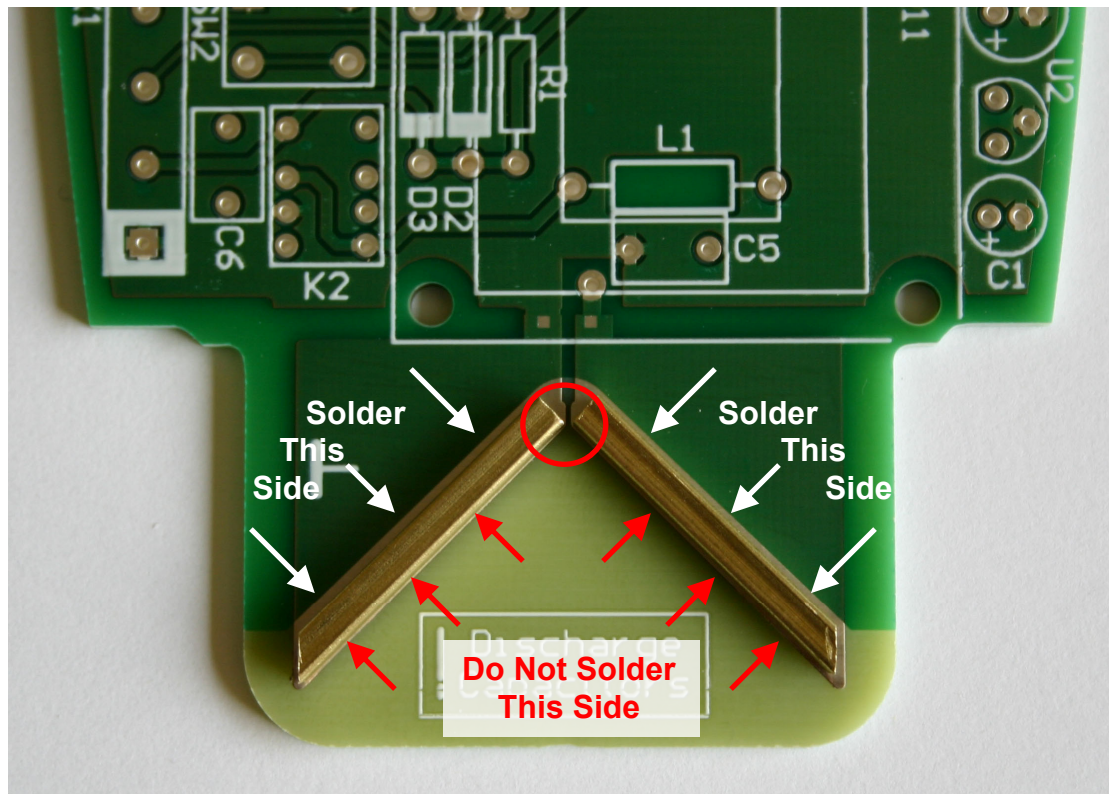
4. It is very important to solder the brass bars in exactly the right position on the board. In the photo above, the gap between the two bars (inside the red circle) should be as small as possible without touching. As a guideline, it should be possible to get a piece of paper in the gap but not a small wire. The bars should be positioned close to the edges of the copper tracks marked by red arrows. This edge will not be soldered – the bars are held down by solder on the other side.

5. To solder the bars, use the wooden peg supplied to hold the bar in place. First put the peg in the middle of a bar, adjust the bar until it is in the correct position then solder the ends of the bar being careful not to move the bar. You will need a hot soldering iron and a little patience as the bar and copper pattern have a high heat capacity. Once the ends are soldered, you can move the peg to one end and solder fillet the whole length of the bar. Take your time soldering the component connector – this is the hardest part of the build and the only part of the PCB that is visible when finished.

Step 5: Component Assembly
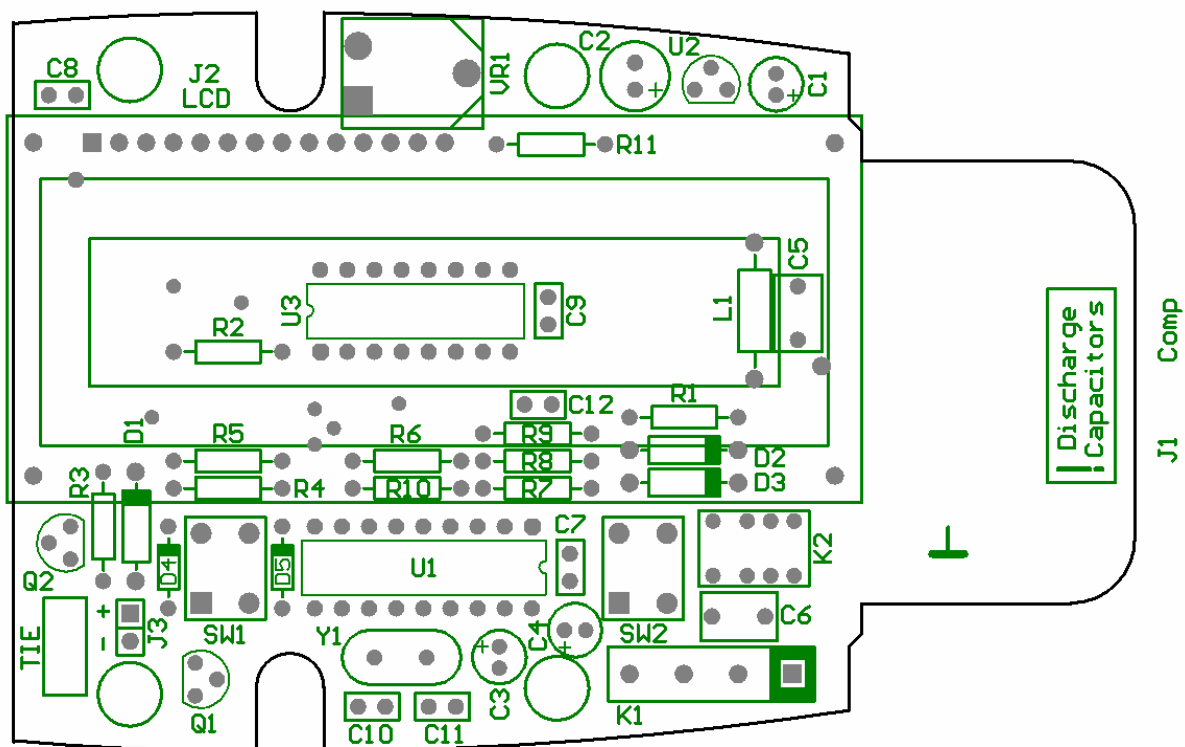
Turn the board so it looks like the diagram above and fit the parts in the following order:
The parts list is shown in Appendix B1. A fully assembled PCB is shown in Appendix C2.

1. Fit all the resistors (R1 to R11) being careful not to mix up the different values. If in doubt, measure them with a multi-meter.

2. Fit inductor L1 (68uH). Refer to the component photographs to correctly identify L1.

3. Fit diodes D1 to D3 (1N4007) and D4 & D5 (1N4148). Ensure they are fitted the correct way round.

4. Fit the socket for U1. Even though it is a socket, make sure the notch is at the correct end.

5. Fit capacitors C7 to C9 (100nF), C10 & C11 (22pF) and C12 (5pF).

6. Fit quartz crystal Y1 (4MHz).

7. Fit Q1 (BC337), Q2 (BC327) and U2 (78L05). Be careful as these devices are very similar.

8. Fit VR1 (2K2 Preset).

9. Fit capacitors C5 (680pF), C6 (1nF, 1%).

10. Fit capacitor C4 (10uF, low ESR). Do not mix this up with the other electrolytic capacitors. It is brown in colour (the others are black). This is a polarised component that needs to be fitted the correct way round. The long lead should be inserted through the hole marked '+' on the PCB legend.

11. Fit capacitors C1 (10uF), C2 (100uF) and C3 (2.2uF). These are polarised components that need to be fitted the correct way round. The long lead should be inserted through the hole marked '+' on the PCB legend.

12. Fit relay K2. It only fits one way round. Solder two corner pins first and check it is flat to the PCB before soldering the rest of the pins.

13. Fit reed relay K1. Depending on the make, the package has a sloped end or a dot / cutout similar to an IC identifying pin 1. Pin 1 goes at the shaded end of the legend.

14. Fit buttons SW1 & SW2. They snap into place with a little pressure. Be careful to get them really flat to the PCB surface.

15. Fit U3 (74LS75). Ensure it is fitted the correct way round. The pins may need teasing inward as they are supplied splayed outwards. DO NOT use an IC socket – U3 must be soldered directly to the board or it could foul the underside of the LCD display.

16. Fit J3 (Battery Clip). First shorten the lead to remove some of the excess length (the lead only has to reach as far as the battery compartment). The correct length is approx. 50mm. Solder the ends to the board using the 2 pads marked J3 (Batt). The positive (red) lead should go to the square pad marked + and the negative (black) lead to the round pad marked –. Make a strain relief for the battery cable with the supplied cable tie as shown in the photo below.

17. Fit U1 (programmed PIC16F648A) in its socket. Ensure it is fitted the correct way round. The pins may need teasing inward as they are supplied splayed outwards.
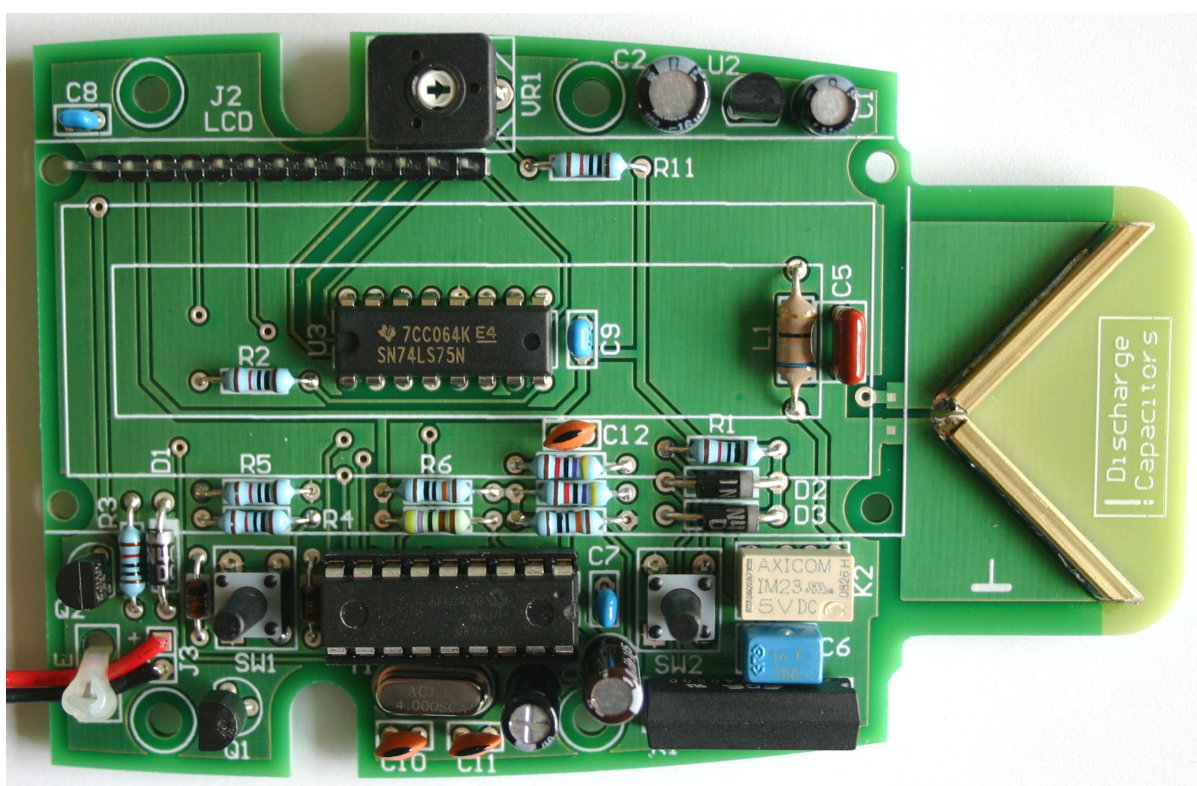
Assembled PCB before LCD is fitted

(J2 has already been fitted in this photo, which is the next step)

Step 6: LCD Display Assembly

The LCD display is fitted above some other components on the PCB and is connected by J2 which is soldered at both ends. Once fitted, it is difficult to remove the LCD to get access to any components below. Before fitting the LCD display, inspect the area beneath the LCD for solder splashes and check that the correct value components are fitted and diodes are the correct way round.

To fit the LCD display…

1. First fit J2 (the display connector) to the PCB. This is a 14 pin connector which is soldered at both ends. At the LCD display end, there are 16 holes – the connector goes in holes 1-14. Holes 15-16 are not used. It should be impossible to get the connector in the wrong holes because, mechanically, it won't fit any other way when the display mounting screws are in place.

2. Put the 4 mounting screws through the holes at the corners of the LCD display and turn the display upside down so the screws stay in place.

3. Slide a spacer on to each of the 4 mounting screws.

4. Turn the PCB over and carefully place it on the upturned display making sure the connector goes through holes 1-14.

5. Put a nut on each of the mounting screws and tighten. The spacers are a loose fit on the screws and you must ensure the spacers are pushed inboard (away from the PCB edge) when the screws are tightened or they will foul the battery compartment and end panel and the PCB will not fit in the box (see arrows below). The screws don't have to be very tight – you will squeeze down the nylon spacer with excessive force.
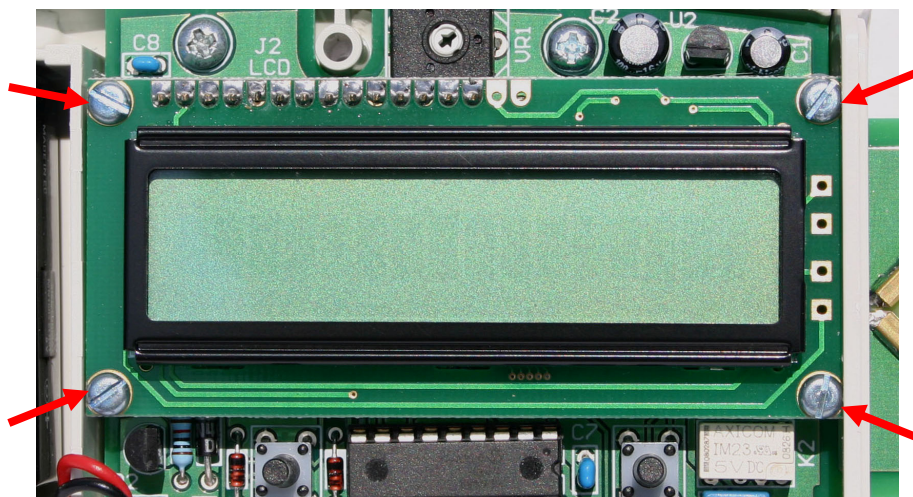
6. Solder the display end of J2 to the LCD display.

7. Cut off the excess length of J2 with wire cutters at the display end (the bit poking up from the display PCB).

8. The 2 display mounting screws at the right hand side of the photo above need to be shortened to avoid fouling the edge of the box. Cut the excess length off with a hacksaw or bolt cutters (or even an old pair of wire cutters). Be careful that the loose piece doesn't fly off and hurt someone – put your hand over the job and wear safety goggles.

Step 7: Testing & Calibration

After assembly the unit needs to be tested before use as follows:

1. With the PCB out of the box and on an insulating surface, attach a battery and press SW1. The power should come on – you may also see something on the LCD.
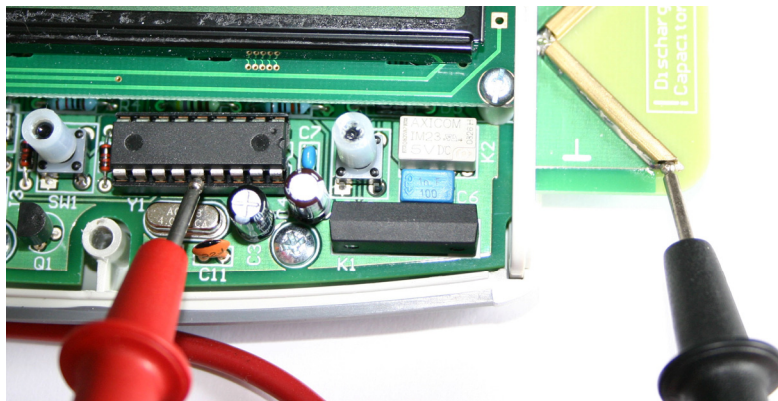
2. Measure the voltage between U1 pin 14 and GND. It should be approximately 5V. If it is not, there is a fault with the power supply on the board – first check the battery is good, then check D1 is fitted the correct way round. If you see a very low voltage on pin 14, check for a short between VCC and GND. If you get 5V only when SW1 is pressed down, refer to the power supply description in the circuit operation section.

3. Peel off the protective film from the LCD display and adjust VR1 for the best contrast. At one extreme, the background will be black. At the other extreme, the text will be very faint.   The optimum contrast is the point at which the background just disappears, so you can read the text but the background is not visible.

4. Next do some basic checks to get confidence that the unit is basically ok *

    *   Switch on the meter. You should see a sign-on message showing the software version followed by "Calibrating…" on the LCD display. After a couple of seconds the calibration procedure should be complete and the meter should be in 'C' mode.

    *   The meter should read zero pF. The reading will be changing slightly with time. Bridging the component connector with your finger should cause the reading to go up. Measuring a known value capacitor should give the expected result.

    *   Press SW1 again. The meter should switch to 'L' mode. You may hear relay K2 clicking in and out when switching between 'C' and 'L' modes. Measuring a known value inductor should give the expected result.

    *   Next test SW2. Measure a component, then press SW2. The reading should go to zero. Take the component away and the reading should go negative by the same amount. For example, if you measure a 100pF capacitor, the reading should say 100pF. After pressing SW2 the reading should be 0pF. When the capacitor is removed, the reading should be –100pF.

    *   If you leave the meter for 2 minutes, it should switch off automatically. Alternatively holding down SW1 will also turn off the meter.

* If your meter doesn't work you may find it useful to read the circuit operation section to help with fault finding.

Step 8: Box Assembly

1. Slide the end panel over the component connector and drop the PCB into the box. You will find the PCB is a snug fit in the box and if you haven't taken care with the placement of the display spacers, the end panel will bow out – refit the display spacers if this happens.
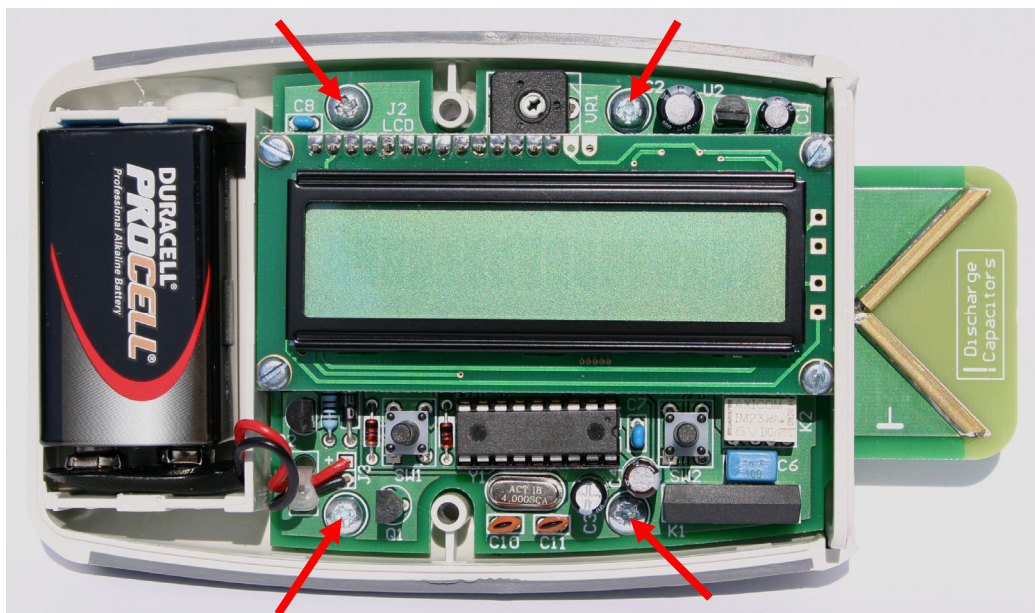
2. Screw the PCB in place with the 4 self-tapping screws provided.
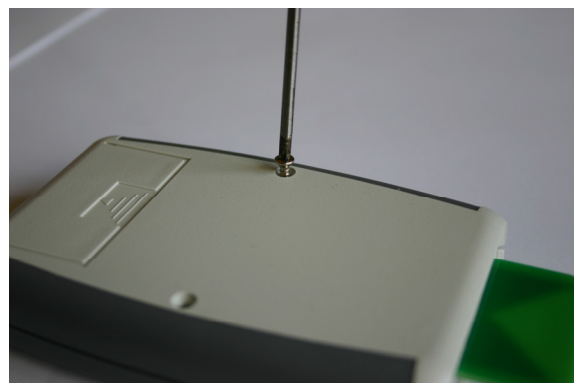
3. Put the top on the case, being careful not to squash the battery lead in the box edges. Fix the top and bottom halves of the box together with the two long screws supplied.

4.   Next, the button spacers must be fitted. Carefully drop the spacers through the button holes in the box top on to the button shafts. Using something flat, press the spacers down until they are flush with the box top. When released, the spacers will poke through the box top by a small amount (the button plunge length).
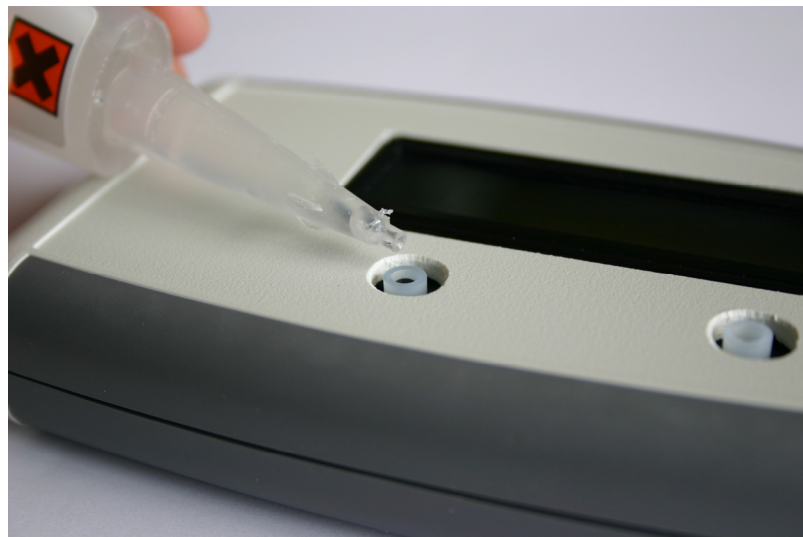
5.   Put a drop of cyanoacrylate adhesive (super-glue) in the middle of the spacer. It will run round the button shaft by capillary action and form a strong bond. If you push the spacer in too far and glue it in place, you will never get the spacer off again, so make sure the spacer is in the correct place before gluing it.

Step 9: The Box Top Label

The label for the box top is made as follows:

1. Find a clean, well lit, flat surface. Before starting, wash your hands – any tiny bits of dirt will ruin the appearance of the front panel.
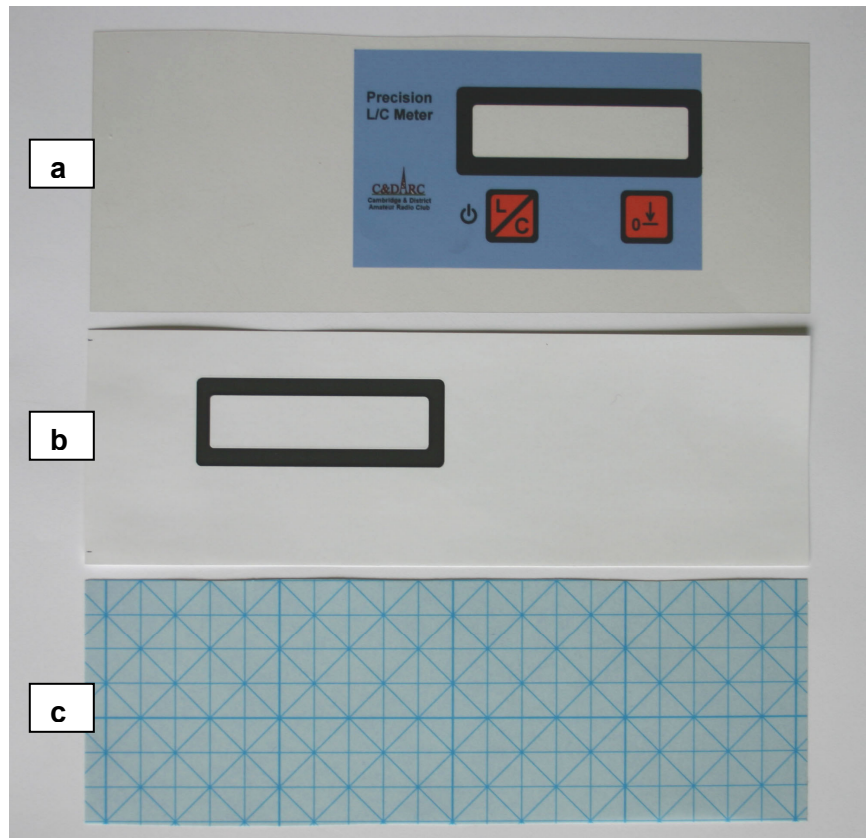
2. The panel is made from 3 layers (see photo above):
   a) A transparent film printed with the buttons and other text. This is the top layer. One side is smooth and shiny – this side will become the final box top (the side the user touches). The other side is rougher and is printed with a reverse image. Be careful not to touch the printing when making up the label.
   b) A white plastic sheet printed with a template for the display bezel. One side is printed and the other has a self adhesive backing.
   c) A double-sided adhesive sheet.

   These layers will be referred to as layers (a), (b) and (c) below. Make sure you know which layer is which and are clear about which side is which before starting.

3. Peel off the backing on one side of layer (c) and stick it to the printed side of layer (b) i.e. cover up the printing. The printing will still be visible through layer (c). Trim the excess sticky edge with scissors to make it easier to handle. You now have a sandwich with a (b) and a (c) side.

4. With a scalpel or very sharp knife, cut a square hole for the LCD display. From the (c) side you will be able to see the bezel template – stay slightly outside the bezel's inner edge so the hole is larger than required – layer (a) will cover up the cut edge when finally assembled.

5. Place layer (a) shiny side down on a flat surface i.e. the text will be mirror image. It is important not to get any marks on the panel and not to transfer any surface lumps when it is pressed, so put it on a pad of paper or something similar.

6. Peel the backing off layer (b) and carefully stick it down on the printed (rough) side of layer (a), lining up the display window as closely as possible. The hole in layer (b) and (c) will be larger than the black bezel printing on layer (a) so it is straightforward to line up the pieces. When turned over, the cut edge of the hole on layers (b) and (c) should be covered by the printing on layer (a).

7. Using something made from smooth hard plastic e.g. a screwdriver handle, carefully rub over the whole of the shiny side of the label – as you work the surface, all the tiny glue bubbles will disappear. Be careful the label stays flat and doesn't 'buckle' while rubbing.

8. With scissors, cut the whole label to a rough rectangle slightly bigger than the recess in the top of the box. Don't attempt to cut the curved sides at this point (just cut them straight across but larger than the widest point).

9. Accurately cut the two straight edges to the correct size for the recess in the top of the box. The right hand edge of the display is lined up exactly with the edge of the recess so first cut the right hand side exactly along the edge of the display bezel's black printing. Then place the label in the box recess to judge where to cut the left hand edge.

10. Peel off the other side of layer (c) and carefully press the label into place on the box. Start by pushing the edge of the label against the right-hand edge of the recess, then lay the label down – at this point the bezel of the display should be completely covered by the label and the buttons should line up with their legends on the label.

11. Using a small screwdriver or the back of a knife, press the overlapping label edges into the edges of the box's label recess. Then run a scalpel along the edge to cut the label to fit the curved edges.

12. Clean any fingerprints etc. from the finished label. You may also need to unscrew the lid of the box and clean the back of the display window and/or the LCD display itself. Finally, you will probably need to clean the scissors / knife blade with label remover fluid or similar to get rid of the glue residue.

Finally, check the unit still operates as expected.

Your L/C Meter is complete. We hope you enjoyed building this project.

L/C Meter V1.2 Circuit Operation (How It Works)

This section describes the circuit operation to help with troubleshooting and for general interest. Appendix A shows the full schematic (circuit diagram) of the L/C meter.

Power Supply Section
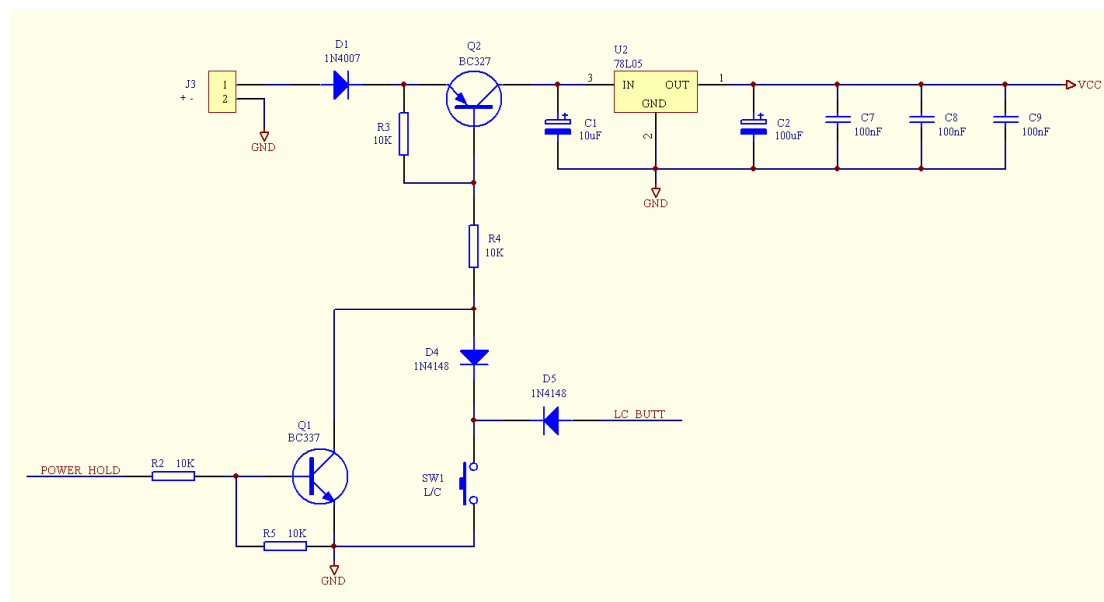
The unit is powered from a 9V battery which is connected to J3. D1 protects the circuit from an accidentally reversed battery. Power is switched on and off by pressing SW1 (the L/C button). This works as follows:

Initially R3 ensures Q2 is turned off and no power flows to U2. As a result there is no power on the microprocessor parts of the circuit ensuring that the signal POWER_HOLD is low and Q1 is consequently in the off state. D5 prevents current flowing to the microprocessor via R3/R4/D4. This ensures a negligible current drain when the meter is off (less than 1uA) to prevent battery drain. D5 also prevents any part of the microprocessor internals drawing enough current to turn on Q2 while the microprocessor is powered down.

When the user presses SW1, Q2 is turned on via D4 and R4. Power flows to the 5V regulator U2 and 5V appears on the VCC line. The microprocessor starts up and the software sets the POWER_HOLD line high. This turns on Q1 ensuring that Q2 is held in the on state after the user releases SW1.

The state of SW1 is sensed by the microprocessor through D5 (there is a pullup resistor inside the PIC on the signal LC_BUTT). When pressed LC_BUTT goes low, when released the pullup pulls LC_BUTT high.

The software turns the power off by pulling POWER_HOLD low. This occurs after 2 minutes of non-activity or when the user holds SW1 down for 2 seconds.

C1 decouples the input of U2. C2 provides bulk storage decoupling for the rest of the circuit. Capacitors C7-C9 provide local decoupling for U1, U3 and the LCD display.

Oscillator Section

The oscillator is the heart of the L/C meter. It is not easy to understand from the real circuit diagram above because the active part of the circuit is inside the PIC. The equivalent circuit is shown below using the same component designators as the real circuit. The PIC pin numbers are also shown, pin 1 being connected to both comparators inside the PIC.

The oscillator is formed by COMP1. COMP2 is just used as a buffer so that loading on FOSC has no effect on the oscillator frequency. R6 and R7 bias the non-inverting comparator inputs to half the supply. Feedback keeps the other comparator inputs within the operating range. C4 prevents L1 shorting out the bias and isolates the bias from the component under test.

L1 and C5 form an LC parallel resonant circuit with a resonant frequency of around 700KHz. In C mode, the component under test adds capacitance in parallel with L1/C5 reducing the frequency. With large capacitors the frequency can get quite low so C4 needs to be a high value requiring an electrolytic capacitor.   However we also need good high frequency performance so we have to use a high quality, low ESR capacitor.

COMP1 switches on every cycle of the sine wave from the LC circuit. As the output switches the fast edge sends a spike of energy through C12 to keep the LC circuit oscillating. Positive feedback from R8 keeps the oscillator running and the network formed by R9 and C3 ensures the inverting input of COMP1 lags behind the non-inverting input. At switch on, C3 takes time to charge up ensuring COMP1 has a known starting state and the oscillator starts reliably.

In L mode, relay K2 reconfigures the circuit so that L1 is in series with the component being tested as shown below.
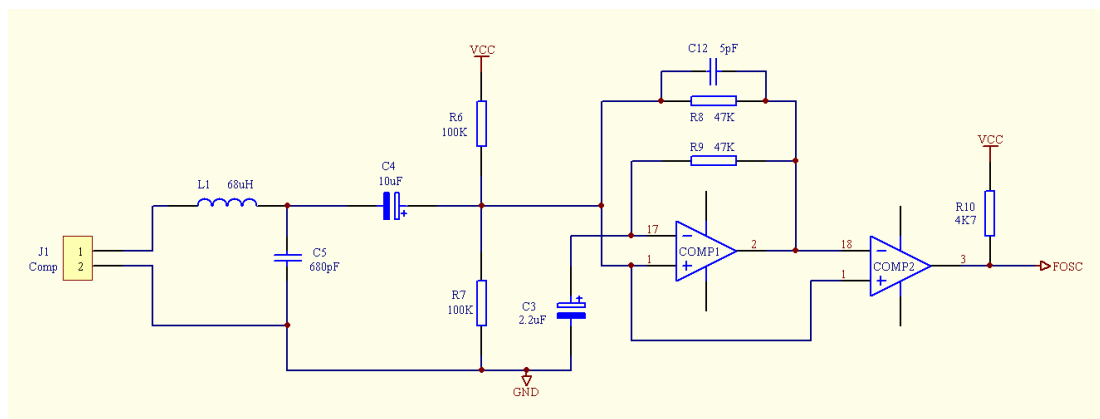

We need to change the configuration because putting low value inductors in parallel with L1 would result in unacceptably high resonant frequencies (over 100MHz) which are outside the comparator's capabilities. With this configuration, adding inductance reduces the frequency as did adding capacitance in C mode.

The function of C6 (shown on the full circuit) is to calibrate the oscillator. It is the only precision component in the circuit and sets the basic accuracy for the meter. Relay K1 switches the capacitor in and out of circuit as if it were a component under test in C mode. The calibration procedure is described in detail in the PIC Software section below.

Diodes D2 and D3 conduct away the high voltage inductive switching spikes which occur when the relays are switched off and could otherwise damage U3.

Microprocessor Section

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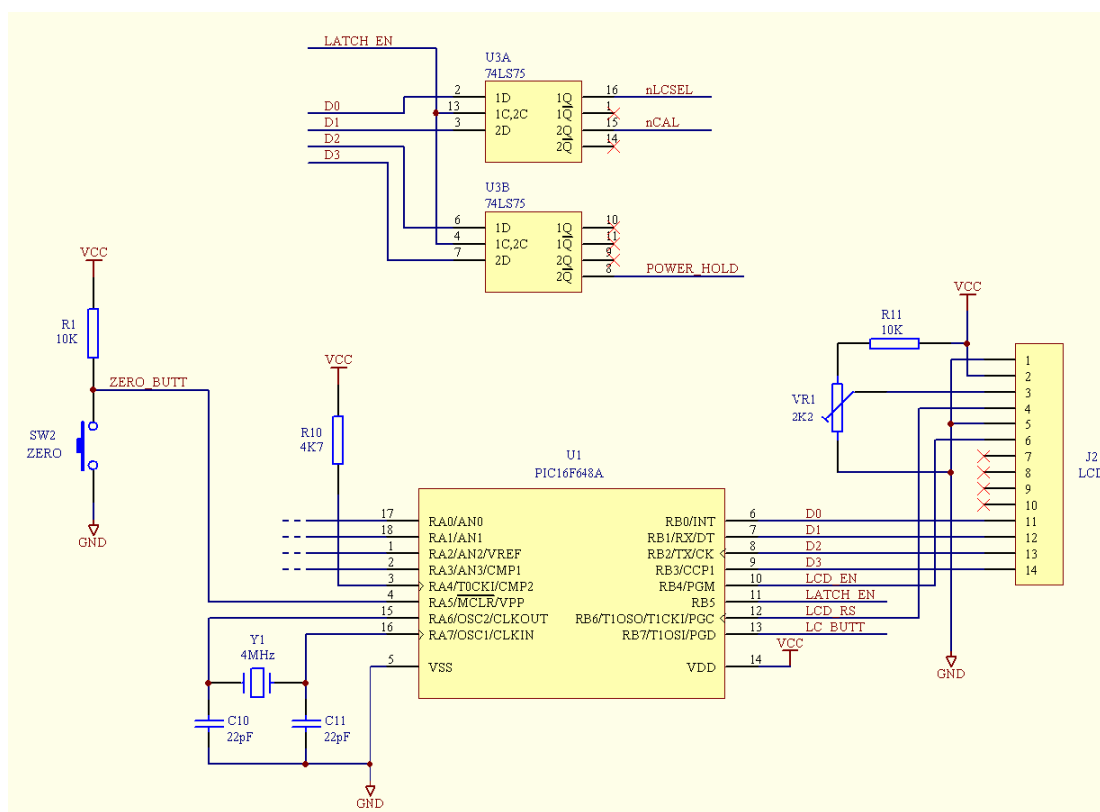
U1 is a PIC microprocessor which runs the meter software. U3 is a latch which is used to increase the number of I/O pins on the PIC. Pins RB0-3 are treated like a data bus and are labelled D0-3 on the circuit. The bus goes to the LCD display and U3. LCD_EN goes high when the software wants to send data to the LCD and LATCH_EN goes high when the software wants to send data to U3. In this way D0-3 are used for two purposes, effectively adding 4 pins to the micro (less LATCH_EN gives a net gain of 3 pins). This only works because we never read from the LCD (pin 5 (R/W) is tied to GND).

VR1 controls the contrast of the LCD display. R11 reduces the range of VR1 so that the display text is still visible at any setting of VR1.

Y1 and C10/C11 are connected to the PIC's internal oscillator circuitry to produce a 4MHz CPU clock. This PIC also has an internal clock but it is not stable enough for this application as we are measuring the oscillator frequency using the CPU clock frequency as a reference.

SW2 (zero button) and R1 are connected to one of the PIC's digital inputs.

PIC Software

With this project the real magic happens in the software. A full description is beyond the scope of this section but the basic principles are described.

To measure the oscillator frequency, one of the PIC's internal counters (we will call it OSC) is connected to the output of COMP2 (see oscillator section) and another is connected to the 4MHz CPU clock (we will call it TIME). The CPU clock is used to wait a fixed length of time (about half a second) after which the OSC counter is stopped. The frequency is then calculated as OSC / TIME.

Ordinarily we can calculate an L or C value from the frequency if we know one of the L/C values. However the accuracy of the meter would depend on how accurately we know the value of the L/C. This isn't too difficult with capacitors but precision inductors are expensive and inductors wound on metal cores are temperature sensitive.

To avoid this problem we use a calibration capacitor. We can derive a formula which effectively compares the frequency with and without the known calibration capacitor against the frequency with the unknown component. The clever thing about this formula is that, since we are only making relative measurements and the value of L doesn't change between measurements, L cancels out and we don't need to know the actual value of L. This means we can use a cheap component for L1 and avoid the problem of knowing the value of L.

The software measures three oscillator frequencies:

F_0 is the frequency with no component connected and no calibration capacitor
F_{cal} is the frequency when the calibration capacitor is switched in circuit
F_x is the frequency with the unknown component connected

In C mode we use this formula for finding the component value:

$$C_x = \frac{\left[\left(\dfrac{F_0}{F_x}\right)^2 - 1\right]}{\left[\left(\dfrac{F_0}{F_{cal}}\right)^2 - 1\right]} \times C_{cal}$$

In L mode we use this formula for finding the component value:

$$L_x = \left[\left(\frac{F_0}{F_x} \right)^2 - 1 \right] \times \left[\left(\frac{F_0}{F_{cal}} \right)^2 - 1 \right] \times \frac{1}{C_{cal}} \times \left(\frac{1}{2\pi F_0} \right)^2$$

Notice how the value of L1 isn't in either formula. Notice also how the value of C5 isn't in either formula. The only capacitor that features is the calibration capacitor C6 which is why we use a 1% tolerance type.

Now we have to consider the effect of stray capacitance and inductance on our results especially on small value components.

In C mode the method we use automatically removes the effect of stray capacitance because the absolute value of C is unimportant. When we measure F_0 the stray capacitance affects the value of C5, but C5 doesn't feature in our equations. During calibration C6 is added to the circuit but C5 and C_{stray} are still in circuit so the change is just the value of C6.

In L mode, when we change the configuration of the circuit the stray capacitance changes. In C mode, L1 is connected to GND. The stray capacitance of the component connector and tracks are in parallel with the LC circuit i.e. they simply add to the C. However when we are in L mode, L1 is connected to the component connector which is shorted with the inductor under test. This effectively isolates the stray capacitance of the component connector and its tracks. The frequencies we measure during calibration are not the same as the values we get in this configuration (the frequency with a zero nH short is higher than in C mode). The ratio of the two frequencies is given by:

$$F_{ratio} = \sqrt{\frac{C}{C + C_{stray}}}$$

where C = Deliberate Capacitance and C_{stray} = Stray Capacitance

When measuring F_0, C = 680pF
When measuring F_{cal}, C = 1680pF i.e. 680pF + the 1nF calibration capacitor
C_{stray} is constant for our PCB layout.

We use this formula to obtain equivalent calibration frequencies for L mode based on the numbers we get in C mode.

Test modes and error messages are described in the User Guide section.

The rest of the software is straightforward – Mode switching and zeroing using the buttons, measurement auto-ranging and driving the LCD display. The only other thing worthy of merit is just how difficult it is to squeeze all the software into the chip. It is all written in C and the maths takes up too much space so in reality the maths becomes even more complex because we cannot afford the luxury of square roots for example.

Appendix A – L/C Meter V1.2 Schematic
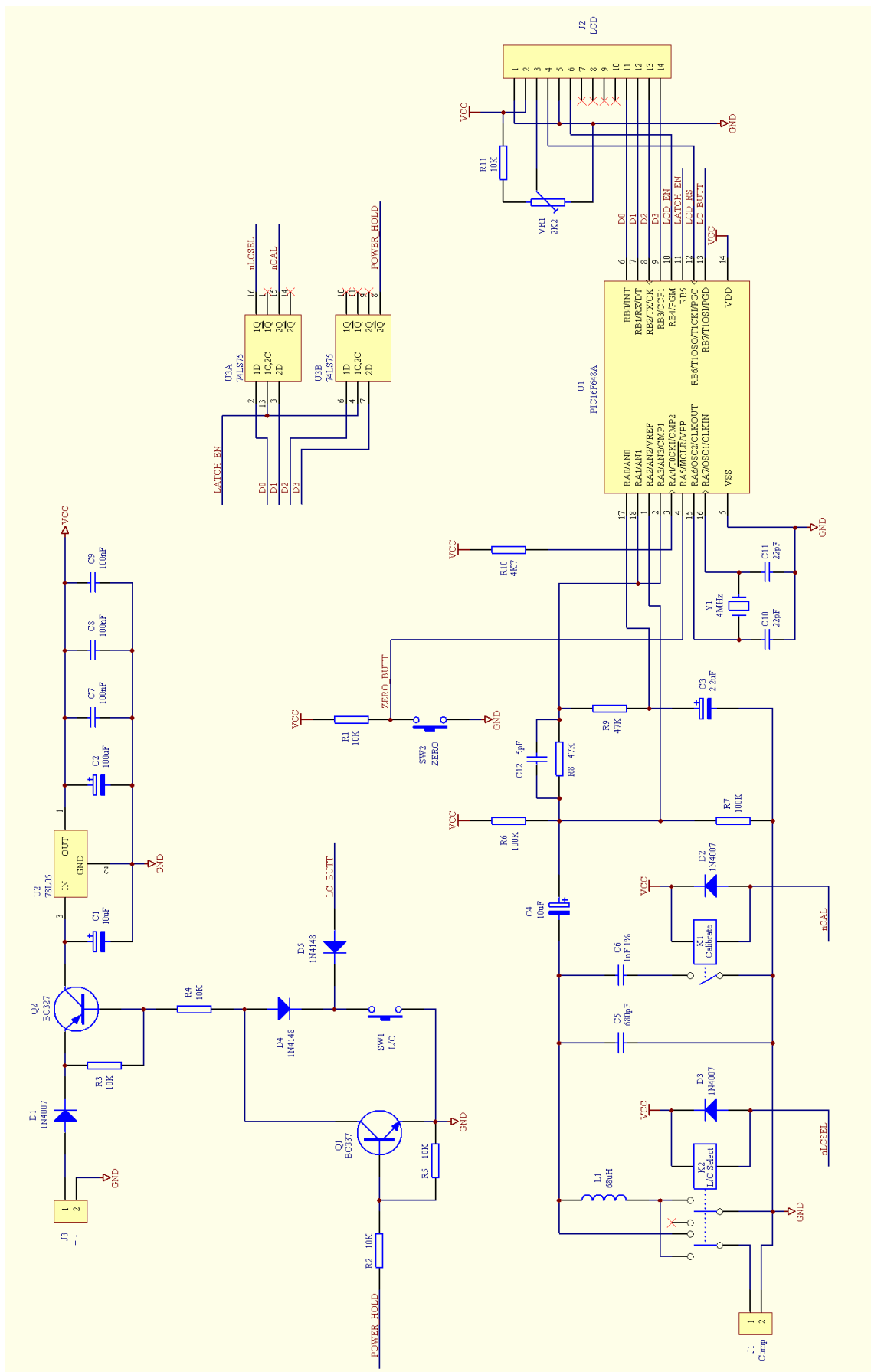
Appendix B1 – PCB V1.2 Parts List

Designator	Part Type	Footprint	Qty	Part Number
R1-R5, R11	10K	AXIAL-0.4	6	RAP 62-0897, RS 148-736
R6, R7	100K	AXIAL-0.4	2	RAP 62-0964, RS 148-972
R8, R9	47K	AXIAL-0.4	2	RAP 62-0942, RS 148-893
R10	4K7	AXIAL-0.4	1	RAP 62-0862, RS 148-663
VR1	2K2	PRESET	1	RAP 67-0220
C1	10uF	CAP_RAD_2P_5D	1	RS 475-9043, FN 945-2281
C2	100uF	CAP_RAD_2.5P_6.5D	1	RS 475-8826
C3	2.2uF	CAP_RAD_2P_5D	1	FN 945-1366, RS 228-6852
C4	10uF, low ESR	CAP_RAD_2P_5D	1	MS 647-UPM1H100MDD, FN 881-2594
C5	680pF		1	FN 119-8308
C6	1nF, 1%		1	RS 117-814, FN 141-3948
C7-C9	100nF	RAD-0.1	3	FN 146-9310, RAP 08-0275
C10, C11	22pF	RAD-0.1	2	FN 941-1674
C12	5pF	RAD-0.1	1	FN 941-1640
L1	68uH	IND_AXIAL-0.5	1	RAP 88-2830, FN 608-531
D1-D3	1N4007	DIODE-0.4	3	RAP 47-3142, FN 956-5051
D4, D5	1N4148	DIODE-0.3	2	RAP 47-3308, FN 956-5124
Q1	BC337	TO-92	1	FN 122-8215
Q2	BC327	TO-92	1	FN 109-7285
U1 *	PIC16F648A *	DIP-18	1	RAP 73-2654, FN 976-0490, RS 623-0320
U2	78L05	VREG_78LXX	1	MS 512-LM78L05ACZX, FN 146-7367
U3	74LS75	DIP-16	1	RS 305-119, FN 110-6076
J1	Component Conn	2 x 23.5mm length	1	2.33mm wide square section brass tube
J2	Display Conn	14 pin 0.1" pitch SIL	1	RS 251-8351
J3	Battery	SIP-2	1	Comes with box
ICSKT1	IC Socket	18 pin IC socket for PIC	1	RAP 22-0134, FN 110-1348
Y1	4MHz	HC49/S	1	RAP 90-1074, RAP 90-0310, FN 146-9647
K1	Calibration Relay	Reed Relay	1	DK 306-1062-ND, FN 108-1682, RAP 60-0670
K2	L/C Select Relay	DPCO Ultra Low Power	1	RS 515-537, FN 162-9004
SW1	L/C Button	6x6mm with long actuator	1	RS 479-1457
SW2	Zero Button	6x6mm with long actuator	1	RS 479-1457
DISP1	Display	16 x 1 Line Alphanumeric LCD	1	Bolymin BC1601A, FN 122-0423
		TOTAL COMPONENTS	**45**	

*   U1 needs to be programmed before assembly. The blank part number is given above.
    Parts supplied in the kit are already programmed.

Appendix B2 – Additional Parts List

| Designator	Description	Qty	Part Number
PCB	Custom, approx. 100mm x 70mm	1	-
Box	ABS with PP3 battery compartment	1	MS 546-1553BGYBAT, RAP 30-3096, FN 100-9442, RS 513-5296
Label Top	HP Premium Transparency Film (Inkjet)	1	EurOffice HP C3835A
Label Backing	Mega Quick-Laser Labels	1	RAP 37-1782
Label Adhesive	Double-sided A4 adhesive sheets	1	HandyHippo.co.uk
PCB Screws	Mounting screws for PCB	4	FN 593-394
Display Spacers *	M3 x 8mm nylon	4	RAP 33-3660, FN 666-889
Display Screws	M2.5 x 16mm	4	RS 483-0063, FN 141-9768
Display Nuts	M2.5	4	RAP 33-1705, FN 141-9446
Button Standoffs *	Standoffs for buttons, M3x8 nylon	2	RAP 33-3660, FN 666-889
Cable Tie	Cable tie for battery cable	1	FN 129-6959

* Note that the display spacers and button standoffs are identical i.e. you will find 6 of the same part supplied.

Parts List Key

| Designator	A unique identifier for this part on the board e.g. R1, C1, Q1 etc. This can be given as a range or list e.g. C1-C3 means C1, C2 and C3.
Part Type	The type or value of the component e.g. 10K, 100nF, 74LS04
Footprint	The shape of the area on the PCB for the component. Often this translates to the package style e.g. the same value of resistor comes in several different sizes, transistors come in standard cases e.g. TO-92 and you can often get the same IC in a DIP or a surface mount package.
Qty	Quantity required on the PCB. A blank indicates that the component is accounted for somewhere else. A quantity of zero indicates that there is a space on the PCB but the component is not fitted in the standard build.
Part Number	Part numbers are for guidance only and all part numbers shown are suitable, however part numbers are listed in order of preference (usually because of price).

Part numbers are prefixed by supplier as follows:

| Prefix	Supplier	Website
FN	Farnell Electronics	http://uk.farnell.com/
RS	RS Components	http://rswww.com/
MAP	Maplin Electronics	http://www.maplin.co.uk/
RAP	Rapid Electronics	http://www.rapidonline.com/
DK	Digi-Key UK	http://dkc1.digikey.com/uk/digihome.html
MS	Mouser Electronics	http://uk.mouser.com/

Appendix C1 – PCB V1.2, Unassembled
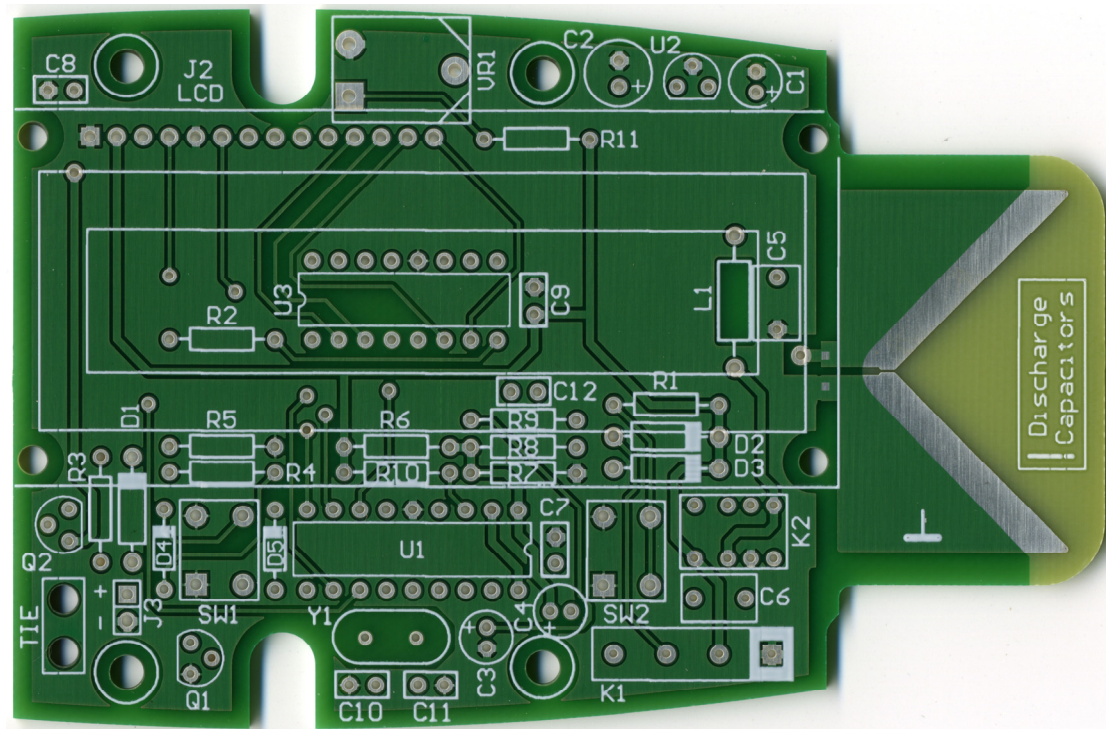
Component Side
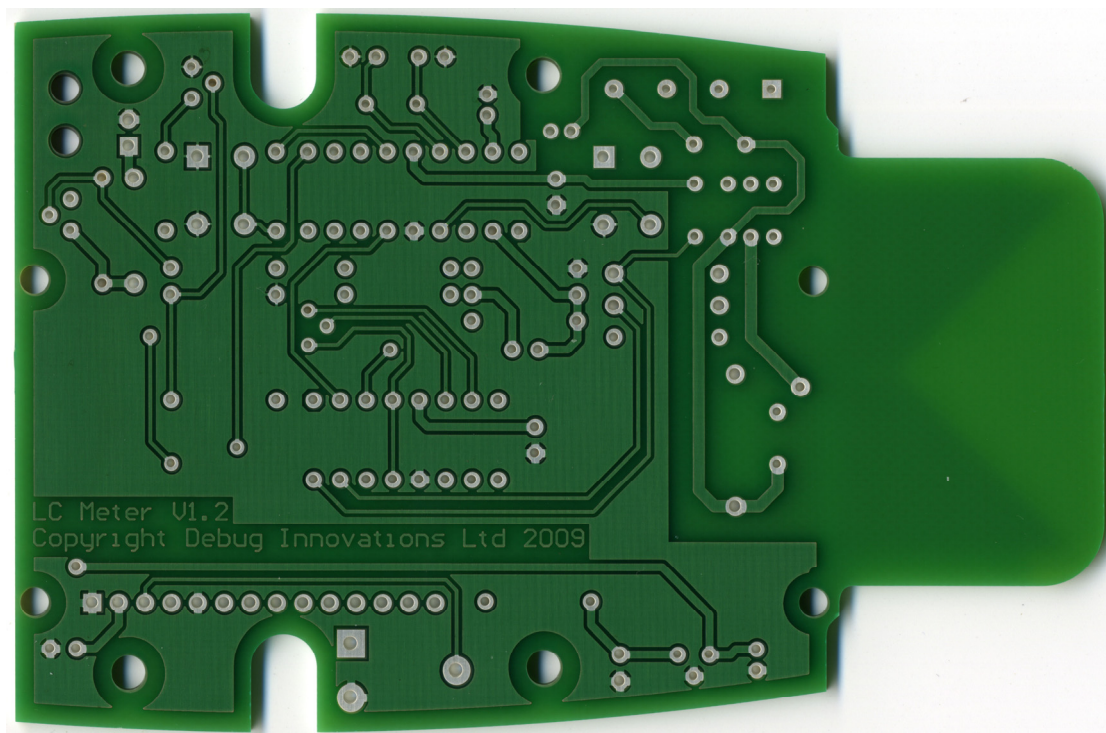
Solder Side

Appendix C2 – PCB V1.2, Assembled
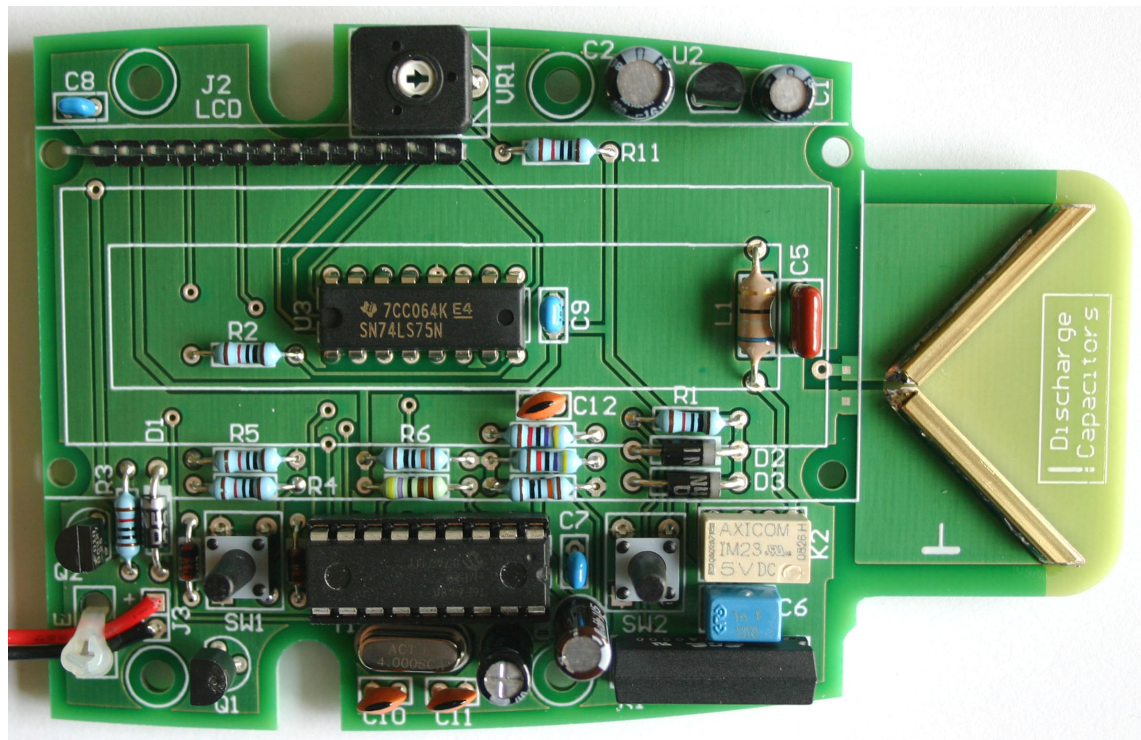
Without LCD Display
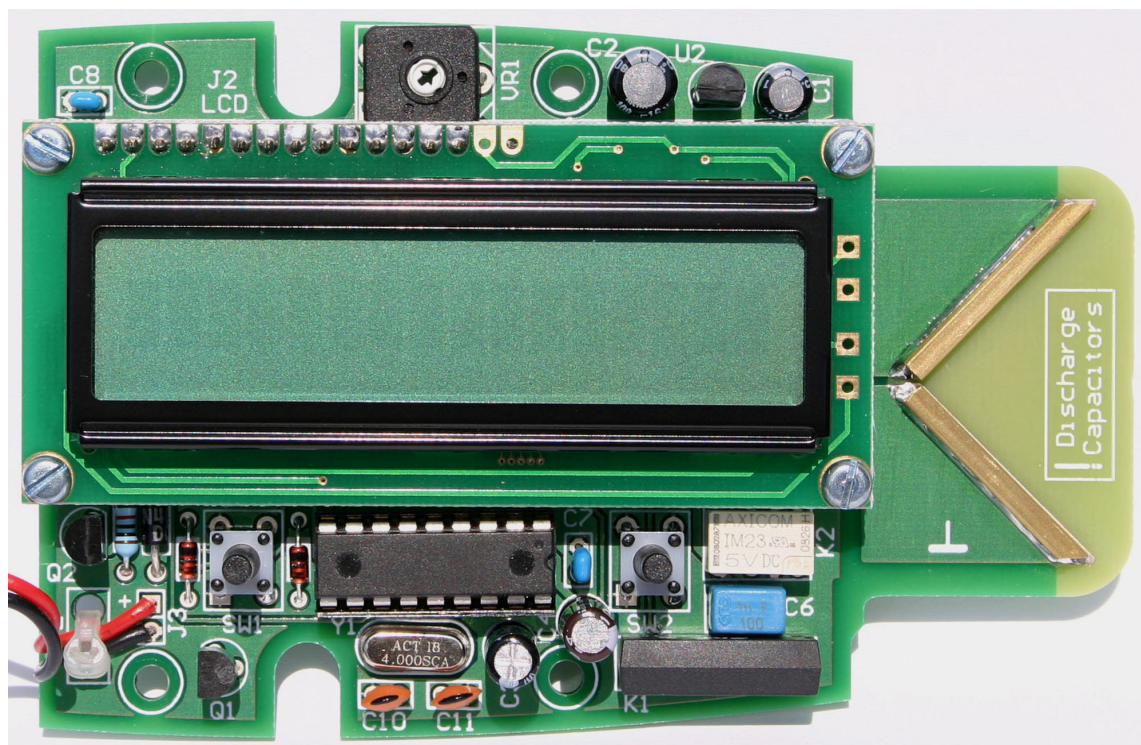
With LCD Display

Appendix D – PCB V1.2 Copper Pattern (not to scale)

Component
Side

Solder Side

LC Meter V1.2
Copyright Debug Innovations Ltd 2009
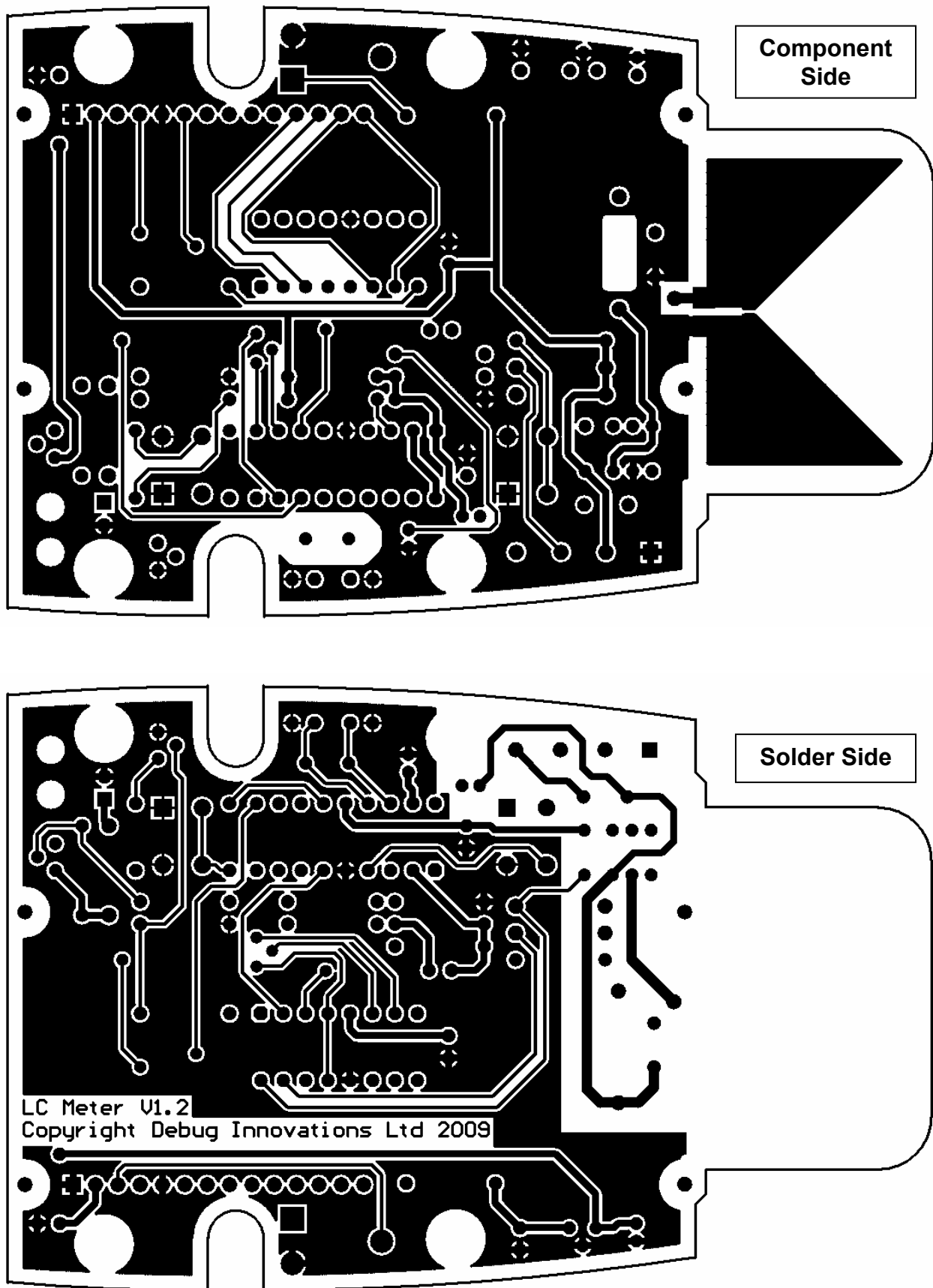
Appendix E – Box Top Drill Drawing
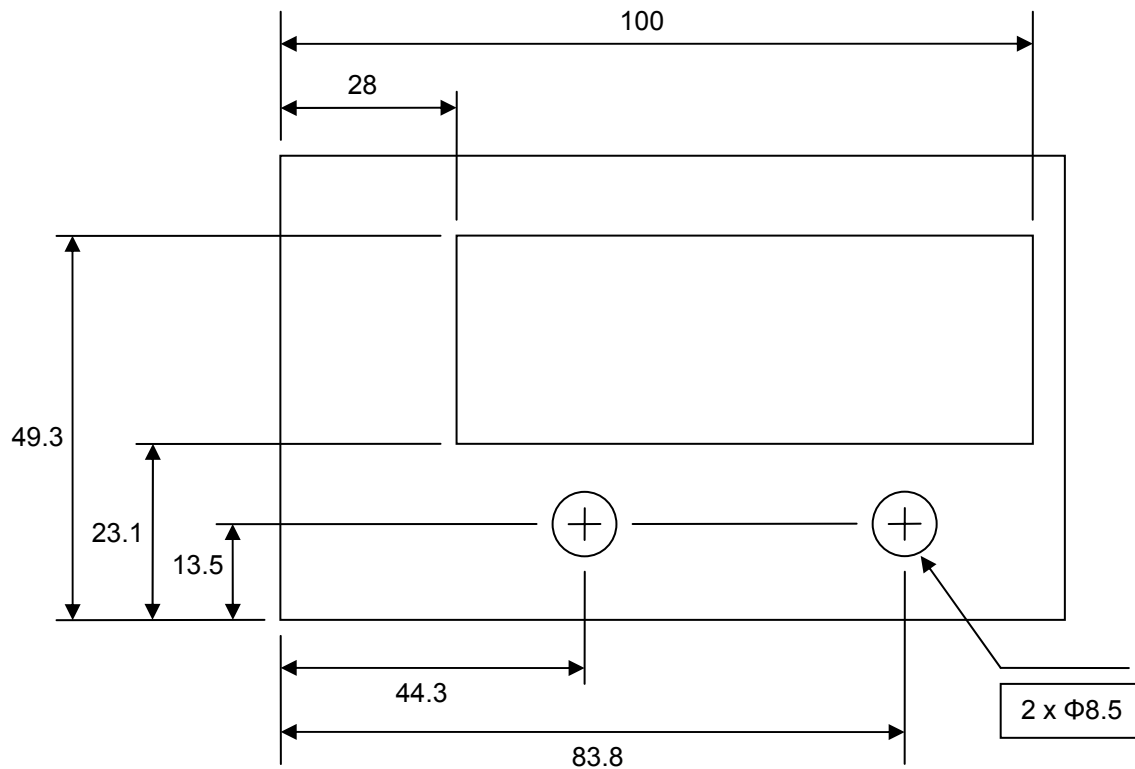
Not to scale, for guidance only. All dimensions in mm. Outer rectangle is label recess, representing widest dimension on curved edges.

Appendix F – Side Panel Drill Drawing
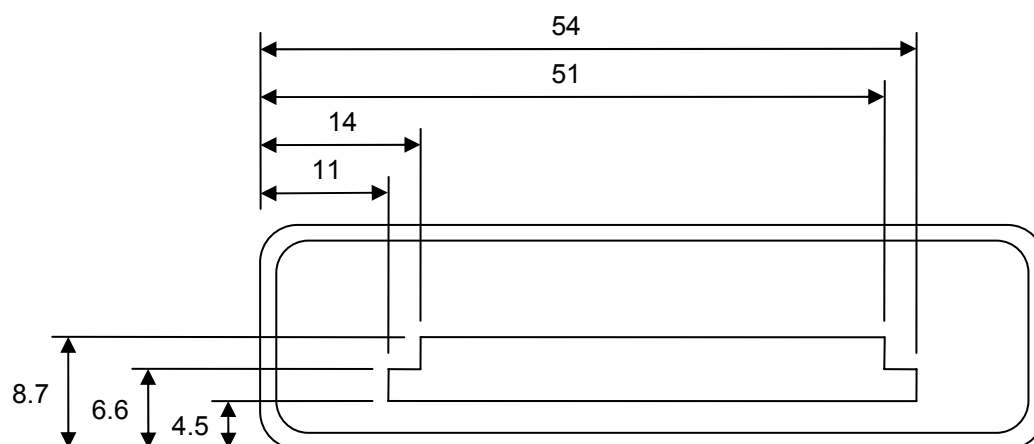
Not to scale, for guidance only. All dimensions in mm.

Appendix G – Resistor Colour Code Chart